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15 June 1964

Prepared under Electronic Systems Division Contract AF 19(628)-500 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



AID 602973

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Quarterly Progress Report

Division 6

Space Communications

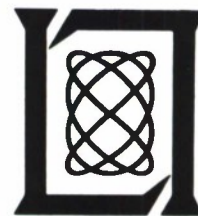
15 June 1964

Issued 15 July 1964

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



INTRODUCTION

This is the fourth Quarterly Progress Report issued since the formation of the Communications Division at Lincoln Laboratory on 1 April 1963 and the start of the Space Communications Program on 1 July 1963. It covers the period from 1 March 1964 through 31 May 1964.

The report includes the work of all groups within Division 6, Communications, with the exception of the work on seismic discrimination in Group 64, which is reported directly to the sponsor in a different form. It also reports on portions of the Space Communications Program undertaken by Division 4, Radar, and Division 7, Engineering.

In addition to the Space Communications activity, other contributions of Division 6 are reported in this document. These include antenna work at Millstone Hill by Group 61 and space probe work by Group 63.

Haystack, which is an interdivisional effort, is reported in detail in the Quarterly Progress Reports of Divisions 3, 4, and 7 and is summarized in this report.

This reporting period was highlighted by the publication of the May issue of the Proceedings of the IEEE which was devoted to West Ford. Eleven papers were prepared by Lincoln Laboratory staff members, giving a full description of the results of the May 1963 experiment. Also included was a paper by Dr. John Findlay of the National Radio Astronomy Observatory.

During the quarter, a single-channel teletype system was demonstrated between Camp Parks, California and Westford, Massachusetts. This was accomplished using a newly developed modulation system which operates at extremely low signal-to-noise ratios. Except for continued measurements of the belt, the West Ford experiment is complete.

Also during this period, much progress was made preparing for several space experiments designed to test, in a natural environment, the techniques and components developed in our Space Communications Program.

The goal of the Lincoln Experimental Satellite (LES) program is the development of a small, lightweight, all solid-state, extremely reliable active repeater. These research satellites will serve as a test bed for the space techniques and components developed in the Space Communications Program and will be carried as piggyback payloads on the USAF Titan 111

vehicles. The Lincoln Experimental Terminal (LET) will serve as a test bed for the ground techniques and components developed in the Space Communications Program. Particular emphasis will be placed on the use of new modulation techniques to provide reliable, jam-free communications even at low signal-to-noise ratios. This terminal will be used in experiments with LES and with other satellites.

15 June 1964

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Head, Division 6
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Accepted for the Air Force
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REPORTS BY AUTHORS IN DIVISION 6

15 March through 15 June 1964

PUBLISHED REPORTS

Technical Reports

TR No.				DDC and Hayden Nos.
338	The West Ford Antenna System	B. F. LaPage	6 December 1963	DDC 438879
343	Project West Ford Payload Telemetry System	W. T. Higgins L. A. Jacobson J. B. Rankin	20 January 1964	DDC*
347	Probability Distribution of Antenna Gain for Satellite with Switched Antenna System	R. N. Assaly	4 February 1964	DDC*

Group Reports

No.				
1964-5	Sequential Decoding on a Channel with Simple Memory	J. E. Savage	2 April 1964	DDC 437163 H-575
1964-15	The Representation of Seismic Waves in Frequency-Wave Number Space	E. J. Kelly, Jr.	6 March 1964	DDC 433611 H-569
1964-17	Spectra of Vocoder Channel Signals	C. M. Rader	4 May 1964	DDC 600185 H-580
1964-20	Scattering Matrix of a Modified (Five-Port) Turnstile	J. A. Kostriza	24 April 1964	DDC 439484 H-577
1964-22	Proposal for 7.75 - 8.35 kMcps Diplexer Using Side-Wall Couplers and Cut-Off Guide	J. A. Kostriza	24 April 1964	DDC 600332 H-581
1964-25	Haystack-West Ford Intersite Coupling Link	J. E. Gillis	14 May 1964	DDC* H-585
1964-26	A Remark on Orthonormal Bases of Continuous Functions in a Hilbert Space	T. S. Pitcher	12 May 1964	DDC 600534 H-582

* Not yet assigned.

Journal Articles*

JA No.

2070	Instantaneous Spectra and Ambiguity Functions	M.J. Levin	Trans. IEEE, PTGIT <u>IT-10</u> , 95 (1964)
2189	Partitioned IR Cell	R. Teoste	Infrared Phys. <u>4</u> , 43 (1964)
2204	Band-Pass Filters with Linear Phase	R.M. Lerner	Proc. IEEE <u>52</u> , 249 (1964)
2226	Optimum Power Division in Coherent Communication Systems	H.L. VanTrees	Trans. IEEE, PTGSET <u>SET-10</u> , 1 (1964)
2231	A Technique for Achieving High Bit Packing Density on Magnetic Tape	J.E. Gillis	Trans. IEEE, PTGEC <u>EC-13</u> , 112 (1964)
2297	Signal Design for Dispersive Channels	R.S. Kennedy I.L. Lebow	IEEE Spectrum, No. 3, 231 (1964)
2317-2	The West Ford Experiment - An Introduction to This Issue	W.E. Morrow, Jr. T.F. Rogers	Proc. IEEE <u>52</u> , 461 (1964)
2317-3	Orbital Properties of the West Ford Dipole Belt	I.I. Shapiro H.M. Jones [†] C.W. Perkins	Proc. IEEE <u>52</u> , 469 (1964)
2317-4	Measured Physical Characteristics of the West Ford Belt	F.E. Heart D. Karp A.A. Mathiasen F. Nagy, Jr. W.R. Crowther W.B. Smith	Proc. IEEE <u>52</u> , 519 (1964)
2317-5	RF Characteristics of Thin Dipoles	C.L. Mack, Jr. B. Reiffen	Proc. IEEE <u>52</u> , 533 (1964)
2317-6	The West Ford Belt as a Communications Medium	I.L. Lebow P.R. Drouilhet, Jr. N.L. Daggett J.N. Harris F. Nagy, Jr.	Proc. IEEE <u>52</u> , 543 (1964)
2317-7	Effects of the West Ford Belt on Astronomical Observations	D.C. MacLellan W.E. Morrow, Jr. I.I. Shapiro	Proc. IEEE <u>52</u> , 564 (1964)
2317-8	The West Ford Payload	P. Waldron D.C. MacLellan M.C. Crocker	Proc. IEEE <u>52</u> , 571 (1964)
2317-9	West Ford Radar and Microwave Equipment	B.E. Nichols D. Karp	Proc. IEEE <u>52</u> , 576 (1964)

* Reprints available.

[†] Division 4.

Published Journal Articles (Continued)

JA No.			
2317-10	West Ford Antenna and Feed System	B.F. LaPage E.W. Blaisdell * L.J. Ricardi	Proc. IEEE <u>52</u> , 589 (1964)
2317-11	The Antenna Pointing System for West Ford	F.E. Heart A.A. Mathiasen	Proc. IEEE <u>52</u> , 599 (1964)

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2046A	Asymptotically Optimum Quantizers and Optimum Analog to Digital Converters for Continuous Signals	L.I. Bluestein	Accepted by Trans. IEEE, PTGIT
2233	The Analysis of the Abrupt Junction Varactor Doubler as a Function of Frequency	A.I. Grayzell	Accepted by Trans. IEEE, PTGCT
2292	Estimation of a System Pulse Transfer Function in the Presence of Noise	M.J. Levin	Accepted by Trans. IEEE, PTGAC
2333	A Note on Buzz-Hiss Detection	B. Gold	Accepted by J. Acoust. Soc. Am.
2334	The Band Pass Compressor: A New Type of Speech Compression Device	B. Gold C.M. Rader	Accepted by J. Acoust. Soc. Am.
2346	Some Non-Central F-Distributions Expressed in Closed Form	R. Price	Accepted by Biometrika
2351	The Frequency Dependence of the Powers and Impedances of Varactor Frequency Multipliers	A.I. Grayzell	Accepted by Proc. IEEE (Correspondence)
2355	The Bandwidth of the Abrupt Junction Varactor Frequency Doubler	A.I. Grayzell	Accepted by Trans. IEEE, PTGCT

Meeting Speeches[†]

MS No.			
974A	Some Recent Applications of Statistical Inference in Radar and Communications	P.E. Green, Jr.	IEEE, Raleigh, North Carolina, 17 April 1964
1005	The West Ford Antenna System	B.F. LaPage	IEEE, Washington, D.C., 17 March 1964

* Division 7.

[†] Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Meeting Speeches (Continued)

MS No.

1040	A New Fourier Technique for Frequency-Domain Synthesis of Delay-Line Filters	J. Max	7th Midwest Symposium on Circuit Theory, University of Michigan, 4-5 May 1964
1048	Taut Wire Delay Lines	G.H. Ashley	Acoustical Society of America, New York, 6-9 May 1964
1053	A Note on Buzz-Hiss Detection	B. Gold	
1054	The Band Pass Compressor	B. Gold C.M. Rader	
1055	A Study of Vocoder Filters by Computer Simulation	C.M. Rader	
1056	A Compact Pitch Computer	N.L. Daggett B. Gold	
1057	Self Synchronized Vocoder Digital Transmission Systems	J.A. Dumanian	
1058	Some Work on Channel Vocoder Excitation	J. Tierney	
1098	Studies of Teleseisms Using Arrays	P.E. Green, Jr.	14th Annual Earth Sciences Orientation Session, Dallas, Texas, 9-12 June 1964
1129	West Ford Terminal Equipment	R.V. Locke, Jr.	IEEE, PTGAP and PTGSET, Palo Alto, California, 26 May 1964

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GROUP 61

I. SWITCHED-BEAM ANTENNA SYSTEM FOR SATELLITE COMMUNICATIONS

The Lincoln Experimental Satellite (LES) antenna system design is a modified version of the original switched-beam antenna system for a randomly oriented satellite. It consists of 8 circularly polarized X-band antennas, each of which is located in the center of a triangular panel and joined by a switching system capable of connecting any single antenna to the transmitter and the receiver. Initially, it was suspected that two different antenna designs would be required, one for low altitude and one for high altitude satellites. Recent experimental data have shown that a single antenna design provides satisfactory performance for satellites at practically any altitude. The design of this 8-element switched-beam antenna system, manufacturing drawings and positioning of the component parts in the satellite, and the layout of the interconnecting semi-rigid coaxial transmission lines have been completed and the components are being manufactured.

The single-pole 4-throw, and the single-pole 2-throw switches are being modified so that they may be mounted on the satellite frame. In addition, a transformer has been designed to improve the input VSWR of the single-pole 4-throw switch. This should reduce the insertion loss at 8350 Mcps from 5.5 db to approximately 4 db, and at the same time it should have a negligible effect on the 0.5-db insertion loss at 7750 Mcps.

The diplexer has evolved into a Tee junction with a four-cavity filter located in each arm of the Tee. The measured isolation between the transmitter and receiver ports at both 7750 and 8350 Mcps is 80 db. The insertion loss at the center of each band is approximately 0.3 db. Unfortunately, recent investigations revealed that Teflon deteriorates when used in satellite applications similar to those for which the LES is intended, consequently the Tee junction will be re-designed to use Tellite rather than Teflon as the dielectric support material.

II. TELEMETRY ANTENNA

In addition to the change in size of the satellite from approximately 24 to 26 inches in diameter, the telemetry frequency has been changed from 240 to 237 Mcps. Although these changes have a negligible effect on the antenna radiation patterns, the change in the matching networks constitutes a major development. That is, the length of the radiators has been restricted to approximately 0.03 wavelength to prevent an undesirable shadowing of the solar cells. In spite of several attempts to increase the radiation resistance and decrease the frequency sensitivity of such a short antenna, it has been impossible to achieve a bandwidth greater than 0.1 Mcps. Although the change in frequency and satellite size necessitated a change in the matching circuitry, these performance characteristics are satisfactory for the first Lincoln Experimental Satellite.

The stub antenna on the LES rhombicuboctahedron has been approximated by an annular slot on the surface of a sphere, and the resulting radiation patterns have been calculated. The agreement with the measured radiation patterns is exceptionally good. In order to obtain some

GROUP 61

information pertinent to the design of arrays of annular slots or short stubs on a sphere, the mutual impedance between pairs of slots will be calculated during the next quarter.

III. WEST FORD TRACKING SYSTEM

Initial evaluation of the tracking system of the East Coast West Ford antenna system indicates satisfactory performance. Further evaluation of this feed system will be carried out by Group 62.

IV. LINCOLN EXPERIMENTAL TERMINAL (LET)

The present feed consists of a standard horn reflector that illuminates a section of cylindrical waveguide which is terminated in a fin-loaded aperture. Radiation pattern and gain measurements indicate that the efficiency of a 15-foot-diameter paraboloid illuminated by this feed will be rather low. A theoretical analysis of the same feed without the fin loading in its aperture indicates that the antenna efficiency can be increased from 50 percent to approximately 72 percent. Accordingly, the present feedhorn is being modified and will be tested during the next quarter. A parallel program using a scale model of the LET (5-foot-diameter paraboloid operating at 35 Gcps) will permit a more convenient and detailed evaluation of the antenna efficiency.

The system requirements specify that the antenna shall radiate circularly polarized signals and be capable of generating tracking-error signals. In order to achieve this, particular modes must be excited in the conical horn reflector feed. The development of the required mode exciter and the polarization transducer is approximately 80 percent complete. The major portion of the remainder of the circuitry consists of stop-band filters which permit diplexing operation of the antenna. These filters have been designed and the development of a prototype unit is nearly complete.

V. HORN REFLECTOR ANTENNA AND GAIN STANDARD FOR THE HAYSTACK HILL RADAR SITE

A 20-foot-long horn reflector antenna with an aperture of approximately 65 square feet will be used in conjunction with the Haystack Hill antenna as a calibrated gain standard. It will be located at the Haystack Hill antenna site and mounted with its major axis horizontal and capable of rotating about this axis. The gain of this antenna was measured very carefully at 20 different frequencies in the range 2.7 to 16 Gcps. The measurements were made with the antenna linearly polarized in both the horizontal and vertical directions. A fourth-degree polynomial was matched to the data with a "least-squared" fit. The standard deviation between the data points and the computed curve is 0.16 db and the peak deviation is 0.35 db. This measurement program has been completed and the horn reflector is being installed at the Haystack Hill site. The results will be presented in a forthcoming technical report.

VI. MILLSTONE HILL RADAR

The cruciform-septum horn for the 12-horn monopulse feed system will be delivered during the next quarter. After replacing the present feedhorns with this improved design, the antenna system will be evaluated.

VII. COMPUTER PROGRAMS

Several computer programs have been written to support the theoretical investigation of RF components and antenna design. These include:

- (a) Input impedance of a single-pole, 4-throw, diode switch
- (b) Characteristic impedance of a two-dielectric medium coaxial line
- (c) Radiation pattern of a fin-loaded circular waveguide aperture and an array of helices
- (d) Radiation patterns of annular slots on a sphere.

SURFACE TECHNIQUES AND EQUIPMENT

GROUP 62

I. LINCOLN EXPERIMENTAL TERMINAL (LET)

A. Microwave Equipment

The microwave equipment design has been completed and most of the components have been ordered. A Varian Associates 10-kw klystron, tunable from 7.7 to 8.4 kMcps, has been ordered to replace the Varian 849 tube which was to be installed initially. It will be driven by a traveling-wave tube amplifier. Exciter signals will be generated in a crystal mixer from a 60-Mcps IF and a stable X-band carrier source. A parametric amplifier (designed and constructed by Group 46) will serve as the receiver front end followed by a crystal mixer for translating the signals back to the 60-Mcps IF. Most of the required ancillary test equipment has been ordered. Designs have been completed on the receiver and transmitter control and calibration systems, and components have been ordered.

B. Signal Processing

Electrical and mechanical design of the LET signal-processing equipment has continued. Some important results are:

- (1) A technique for packaging digital microcircuits has been devised which retains flexibility, ease of assembly, and yields a reasonable packing density.
- (2) The electrical design for major portions of the frequency synthesizer, the vocoder, and the sequential encoder-decoder has been completed.
- (3) With the aid of a manufacturer, the "box-ear" matched filter required for the channel receivers has been realized as a crystal filter.
- (4) Nearly all major components and instrumentation have been ordered for delivery during July and August.

II. SPEECH PROCESSING

A. Band-Pass Compressor

Further work on the Band-Pass Compressor (a voice-excited vocoder with compressed base-band excitation) has yielded promising results with high-quality input speech. The compressed excitation was obtained by TX-2 simulation, recorded, and then tested on the Laboratory vocoder. Experiments now in process will determine the Band-Pass Compressor's performance with carbon-button telephone-quality input speech.

B. Phase Distortion in Pitch-Excited Vocoders

In a channel vocoder, the phase-vs-frequency characteristic of the vocoded speech is little different from the phase-vs-frequency characteristic of the excitation at the synthesizer input. In a pitch-excited (as opposed to a voice-excited) vocoder, this excitation is a sequence of pulses whose phase characteristic is essentially constant with frequency, a characteristic altogether

different than that of natural speech. A technique for reducing this phase distortion has recently been developed on a computer simulation of a spectrally flattened channel vocoder. A rudimentary formant vocoder is inserted between the exciting pulses and the synthesizer. Such a vocoder is an analog of the vocal tract and thus alters the phase of the excitation to conform more with natural speech phase. Amplitude distortion caused by the formant vocoder is removed by the spectral flattening. The quality of vocoded speech from the 26-channel computer-simulated vocoder has been noticeably improved by this technique. Alleviation of roughness has also been noted when a cascade of 4 fixed resonators (fixed formants) was inserted in the 16-channel laboratory vocoder.

III. HAYSTACK

The Haystack pointing system was used to direct the 60-foot antenna at the nearby West Ford communications site in a radio astronomy experiment. A formal testing effort was also instituted to obtain system precision estimates as well as to discover possible malfunctions.

The individual programs of the pointing system have continued to receive detailed attention, and first versions of all such individual programs are operational with the exception of the program which deals with earth satellites. Now that this system of programs is operating smoothly, an effort is being made to further simplify the actual use of the system.

Additions to the pointing system are still in progress and may be expected to continue for some time. At present, effort is concentrated in the following areas:

- (a) A joint Division 6 – Division 7 effort has produced an initial version of a master pointing console, with only minor details to be completed. A second version of this console which will provide a more convenient front-panel arrangement is now in progress.
- (b) Connections to radiometric measuring equipment will be made to permit use of the Univac 490 as a signal processor for radiometric boresight experiments.
- (c) A technical agreement has been reached on the intersite coupling link between the Haystack and the Millstone antennas. Parts have been ordered for this intersite coupling link, and design is in progress. This link will permit pointing data to be fed in both directions between the two sites.
- (d) A technical agreement has been reached on the necessary program and equipment changes to permit use of the 490 computer for a Venus radar astronomy experiment.

As an entirely separate effort, a program has been written for processing optical data obtained in measuring the surface of the 120-foot reflector. This program is intended to provide a rapid processing tool for assistance in reflector rigging and to provide an estimate of best-fit parabola.

IV. SITE OPERATIONS

A. West Ford Communications

A single-channel, full-duplex, demonstration teletype system via the West Ford dipole belt was placed in operation between the sites at Camp Parks (Pleasanton, California) and Millstone Hill (Westford, Massachusetts). Land lines from Westford to the Laboratory in Lexington permitted test traffic between the Laboratory and the California site. This terminal equipment

utilizes a 32-symbol alphabet generated by using binary sequences. Various transmission rates are available so that 13, 26, 52 or 104 words per minute can be chosen depending upon the signal-to-noise ratio. This TTY system can operate at 100 words per minute with a signal-to-noise ratio of -2 db in a bandwidth of 2 kcps (the bandwidth of the West Ford channel due to doppler-frequency smearing). This corresponds to an E_b/N_o of 14 db, where E_b is the received energy per bit, and N_o is the receiver noise power density. A demonstration of the system was made early in April with 52 words per minute transmitted west to east, using 40-kw transmitter power at 8350 Mcps in California, and 26 words per minute east to west, using 20-kw transmitter power at 7750 Mcps in Massachusetts. Maser front ends with noise temperatures varying from 60° to 90° K were used with the receivers at each station.

B. Belt Measurements

Several sets of belt contour measurements were made during this reporting period, using the bistatic radar mode of operation transmitting at Camp Parks and receiving at the Millstone site. Results continue to be in essential agreement with theoretical predictions.

C. Lunar Communications

Teletype communication experiments with the Royal Aircraft Establishment (RAE) at Farnborough, England have continued with two-way (nonsimultaneous) 100-word-per-minute test traffic via the moon from the Millstone station. When the RAE installs a diplexer permitting simultaneous operation of their receiver and transmitter, full duplex test operations via the moon will be possible.

SPACE TECHNIQUES AND EQUIPMENT

GROUP 63

I. ACTIVE SATELLITES: ENVIRONMENTAL STUDIES

A new spacecraft surface, which has a low solar absorptivity and high thermal emissivity, has been developed to replace the usual, white, satellite surface coatings. It consists of a thin layer of glass with an aluminized back surface attached to the satellite with an adhesive. This surface has far better handling characteristics than painted surfaces; it is expected to be at least as good as the usual paints in time degradation of the solar absorptivity.

Laboratory facilities are being set up to conduct studies of radiation damage to electronics components; tests are also being conducted at vendor facilities. Various adhesives and individual satellite components for use in the Lincoln Experimental Satellite have been subjected to radiation equivalent to a year's sojourn at 2000-mile altitudes and were found satisfactory.

II. LINCOLN EXPERIMENTAL SATELLITE (LES)

The construction of active repeater satellite research vehicles to be lifted piggyback in the Titan III Research and Development launches is continuing. Two (possibly three) launches are scheduled for early 1965; three more are scheduled for late 1965 and early 1966. The research vehicles in the early launches will go into highly elliptical orbits with apogees of approximately 20,000 nautical miles. Later vehicles will be launched into synchronous orbits.

Proposals for the integration of our payload with the Transtage of the Titan III are being received and evaluated. The Cape Kennedy launch facility was visited and tentative agreements were made on the assembly and spin balancing of our payload and solid booster.

The all solid-state, X-band, repeater-amplifier and antenna switching system to be tested in the early launches are being developed approximately on schedule.

A. Power Supply

Contracts have been awarded for both the solar cell panels and the DC-to-DC converters for the LES program. A solar simulator for testing panels is now operational.

Studies were begun on various phases of the LES booster stage. Laboratory tests on batteries, microswitch contacts, and solar cells were conducted.

B. X-Band Transponder

The over-all performance specifications of the repeater are expected to be:

Transmit frequency	7750 Mcps	Time-delay distortion	<10 nsec
Receive frequency	8350 Mcps	DC power input	12 w
Transmit power out	0.28 w	Receiver noise figure	11 db
1-db bandwidth	20 Mcps	Minimum receiver power	-90 dbm

To aid in acquisition and tracking, a beacon will be transmitted at 7740 Mcps. Provision will be made to detect a command signal to enable turn-off of the telemetry transmitter.

C. Switching Antenna

Proposals have been received from vendors for the infrared earth-sensing system to be used to switch antennas in the transponder. Decision logic for an infrared antenna switching system has been designed and breadboarded. The drivers for the diode switches have been designed and tested.

D. Telemetry

The information-processing portion of the spacecraft telemetry system has been designed for the systems, circuits, and packaging areas. A basic digital-to-analog converter unit has been designed and temperature tested with satisfactory operation from -80° to $+110^{\circ}\text{C}$. Temperature-sensing circuitry has been developed which uses a maximum of 9.5 mw per sensing element.

Breadboard construction of the processing unit is now in progress. Sixty channels of telemetered information will be transmitted at a 100-bit-per-second rate on the first flight. This portion of the system will weigh 4.6 pounds and use 250 mw to power its 6000 components. Packaging density is approximately 100 components per cubic inch.

III. SPACE PROBE INSTRUMENTATION

In cooperation with other agencies and laboratories, work continues on four space probes: Eogo, Mariner C, Gamma Ray Telescope, and Pioneer.

Eogo flight units are being processed at Goddard Space Flight Center. No critical problems have been encountered. The launch of Eogo is still set for 1964.

All Mariner flight units have successfully completed flight qualification tests at the Jet Propulsion Laboratory. The remainder of the program consists of continued flight condition testing of the proof test model at higher stress levels than required for approval.

The prototype unit of the Gamma Ray Telescope has been completely checked out and certified for environmental performance. The flight unit will be delivered in early June for spacecraft integration. The power converter problem which had caused concern during the last reporting period has been solved.

In the Pioneer plasma probe program, the measurement, energy, digital processing, and memory sections have all been designed, breadboarded, and prepared for prototype. Screening specifications are in the process of being met, and bids have been received for supplying power converters.

Some difficulty has been experienced in meeting the weight allotment. The present estimate for the electronics is 45 ounces. There has also been some lag in the program schedule due in part to delays in the delivery of microcircuits.

IV. ADVANCED AND THEORETICAL STUDIES

A. New Transistor Circuit

A feedback amplifier circuit has been designed for use in greatest-of decision circuitry. In application, the circuit can be thought of as a transistor-like device with high input impedance, a current generator output, and extremely high transconductance (about 1 mho for circuits tested). The "base-to-emitter" voltage is a few millivolts.

B. Digital-to-Geometric Series Converter

A circuit technique has been devised which accepts a binary input and generates an analog current output whose levels form a geometric series in which successive levels are in the ratio $r:1$.

A converter was built to accept a 5-bit input with $r = \sqrt[5]{10} = 1.3335$, giving an output current range of 10,000:1. The range of conversion errors is from -2.24 to $+3.19$ percent. With some design modification and careful trimming, this could probably be reduced to ± 0.5 percent.

C. Passive Stabilization Schemes

We are continuing our investigation of the behavior of spinning satellites stabilized by solar pressure acting on various configurations of specular and corner-reflecting paddles, such that the spin axis of the satellite seeks the direction normal to the plane of the ecliptic. This system of satellite orientation is best suited to low-inclination high-altitude orbits, where the plane of the orbit will precess only slowly through the plane of the ecliptic during the lifetime of the experiment. Three methods of antenna orientation may be employed to beam the signal at the earth: (1) a single-axis mechanical servomechanism, (2) an electronically switched antenna array girdling the satellite (this results in a system with no frictional parts), and (3) an "inside-out" satellite in which nearly all of the angular momentum is contained in an internally stowed reaction wheel.

The equations governing the erection of the spin-axis vector for small initial angular misalignments have been solved, and the family of solutions is being investigated on the 7090 computer. With a favorable choice of system parameters (which are themselves not critical), i.e., area of paddles, moment arms, moments of inertia of the satellite, and rate of rotation, it appears possible to reduce any small spin-axis injection error by an order of magnitude within approximately six months. We are also presently investigating the more general case of large injection errors.

D. Level Regulator

As part of the on-board satellite signal-processing program, a level regulator has been tested which introduces at most a 2-db degradation into the signal-to-noise ratio of the signal being processed. This regulator consists of a combination of symmetric limiters, modulators, and filters. The circuit is suitable for incorporation into repeater-amplifier links.

E. Varactor Circuits

The equations have been derived for the degradation in the power output from an up-converter driven by a varactor doubler chain as a function of the VSWR of the load. A computer program has been written to solve these equations for an arbitrary number of doubler stages. A program has also been written which prints out the design parameters and output power as a function of efficiency for a graded junction up-converter.

ANALYSIS

GROUP 66

I. PROPAGATION MEASUREMENTS

A proposal to place in orbit a large, rigid, precisely machined, metallic calibration sphere has been prepared. This sphere is to be placed in a 2000-mile 30° circular orbit by one of the Titan III-A launch vehicles early next year. It is designed to present a one-square-meter optical cross section, and is expected to make possible accurate measurements of attenuation, multi-path and doppler spread at X-band and other microwave frequencies. It will also provide accurate calibration of microwave radar and radio systems.

II. MULTIPLE ACCESS STUDIES

In many contexts (e.g., multiple access to active satellite repeaters), the sum of several modulated sinusoids is modeled as a Gaussian process. It appears that the moments of the envelope of the sum may be found as a function of the number of sinusoids. By comparing these moments with the corresponding moments of a Gaussian distribution, one can quantitatively evaluate the model. Analysis is proceeding on this problem.

Technical assistance was rendered in the evaluation of the design plan of the Random-Access Discrete-Address proposal which is currently being evaluated by the U. S. Army Electronics Command. Particular attention was devoted to the question of system traffic capacities under normal operating conditions and in the presence of jamming.

III. WEST FORD STUDIES

A report is being drafted dealing with the system aspects of possible West Ford channels. This report will complement the material in the West Ford issue of the Proceedings of the IEEE.

IV. COMMUNICATIONS THEORY

The following question occurs in the construction of certain Gaussian noise processes: given an orthonormal set (φ_i) of continuous square integrable functions, when can the set be completed by the addition of only continuous functions? We have shown that this can always be done if the set (φ_i) is finite and cannot always be done if the set is infinite.*

Let (p_i) and (p_{ij}) be the initial probabilities and transition probabilities of an ergodic, countable-state Markov process (a_i) . Assume that

$$\alpha = - \sum_i \sum_j p_i p_{ij} \log p_{ij}$$

is finite. Then, under appropriate further assumptions, we can prove the following theorems:

*T. S. Pitcher, "A Remark on Orthonormal Bases of Continuous Functions in a Hilbert Space," Group Report 1964-26, Lincoln Laboratory, M.I.T. (12 May 1964), DDC 600534, II-582.

Theorem 1.

For almost every x ,

$$\lim_{n \rightarrow \infty} \frac{1}{n} \log P \{a_1 = a_1(x), \dots, a_n = a_n(x)\} = -\alpha \quad .$$

Theorem 2.

Let ω be the measure defined on $[0, 1]$ by:

$$\omega \{[0, x]\} = P \left(\frac{1}{a_1} + \frac{1}{a_2} + \frac{1}{a_3} + \dots < x \right) \quad .$$

There exists a set C with $\omega(C) = 1$ and

$$\dim C = \frac{\alpha}{-2 \int_0^1 \log x \omega(dx)}$$

where $\dim C$ is the Hausdorff-Besicovitch dimension of C .

A procedure involving the use of error-correcting codes for transmission of information at varying rates has been described by Weiss.* The class of codes considered lends itself to an analysis of sub-blocks of code sequences; but there are more powerful and efficient classes of codes known. Thus, a study has been undertaken of Bose-Chaudhuri codes from the point of view of varying the ratio of information bits to total bits. It appears that this should be done by selecting only certain coordinates from some basic code (such as a maximal length shift register code) rather than by taking sub-blocks.

V. SYSTEMS STUDIES

Preliminary work has started on operations planning for the experiments to be performed with the LES and LET facilities and also on a comparative study of the relative merits of various active satellite systems.

*E. Weiss, "Generalized Reed-Muller Codes," Inform. and Control 5, 213 (1962).

DIVISION 4

RADAR

I. HAYSTACK

During the past quarter, the reflector panels of the Haystack antenna were installed, surveyed, and adjusted. The contour of the surface in the face-up position has been biased so that it will have minimum errors when the reflector is tilted at an elevation angle of 45° . At the completion of the surface adjustment, the rms error was less than 0.020 inch from the precalculated contour. Static loading tests on the completely rigged antenna have been completed and there is excellent correlation with the analytic studies. There is now firm evidence to indicate that the performance of the antenna will fulfill, or surpass, the design specifications.

The radiometer plug-in box has been completed and is now installed at the Haystack test dock. Calibration tests, using a rotatable cornucopia horn, are now in progress. These radiometer tests will be followed by pattern and gain measurements of the Haystack antenna at 3, 8, and 16 kMcps during the month of July.

The cable interconnection system is now approximately 90 percent complete and will support the initial operating test schedule in July. The water and air piping system has also been installed within the antenna structure.

The communications-radar box has been modified to accept the transmitting and receiving components. These components will be ground tested during June and will be installed in the plug-in box during July. The 1-Mw power supply has been assembled and is now being tested.

The digital pointing computer has been integrated into the site, and the interface connections to the control console and site timing system have been completed. The computer and the computer programs have been exercised with the 60-foot West Ford reflector located approximately 1.2 miles away.

An active experimental program will start at the Haystack site in midsummer. Much of this early activity will be associated with calibration and evaluation testing of the antenna, its pointing system, and the high-power transmitter system.

II. SPACE COMMUNICATIONS: LOW-NOISE RECEIVERS

The Stirling cycle refrigerator has not been delivered. A Joule-Thomson-type cooler was received. It employs no moving mechanical parts in the refrigerating section. The compressor can be located at some distance from the cryostat, permitting a more convenient mechanical layout in many site installations. Performance of this refrigerator and the Stirling machines will be reported as more experience is acquired.

The program of diode evaluation continues. The experience with gallium arsenide has begun to assume a definite pattern in which the GaAs diodes change very little between room temperature and liquid nitrogen temperature, but degrade considerably between liquid nitrogen and liquid helium temperatures. In all cases the higher the quality of the diode, i.e., the lower its room temperature loss, the more pronounced is the tendency to degrade at very low temperatures.

DIVISION 4

Silicon diodes have exhibited a similar characteristic except that the effect is more pronounced.

Two, electroformed, X-band, parametric amplifiers have been completely assembled and are ready for test and evaluation. We have received four varactors of the type required for this amplifier. It is hoped that, by the next reporting period, we will have operated these amplifiers successfully over the band required for the LET, and that we will have taken the initial steps for integrating them into the Stirling cycle refrigerator.

DIVISION 7 ENGINEERING

I. LINCOLN EXPERIMENTAL TERMINAL (LET)

A. Antenna Vehicle

Design of the main structure of the antenna pedestal is about 75-percent complete, and quotations have been requested for the elevation and azimuth drives. Most of the small items such as drive motors, bearings, hydraulic buffers, and brakes have been ordered, and some of these have already been received. Quotations have been received for the running gear and undercarriage of the antenna vehicle, and the order will be placed shortly. Fabrication of the antenna is nearly complete and delivery is scheduled for the latter part of June 1964.

B. Analog Orbit Computers

The Analog Orbit Computer located at the West Ford communications site is now in operation and undergoing data testing. Preliminary reports indicate that results are as anticipated. Three additional gearboxes for latitude correction, doppler frequency, and mean anomaly correction have been designed and manufactured. These units provide necessary information for data refinement.

A new analog orbit computer, a more compact version of the West Ford unit, is now being designed. The variable speed drive used in the first computer has been redesigned and is now being manufactured. Preliminary designs for approximately 10 other gearboxes have been completed. A single readout unit will be used for this computer. By means of various switch gear, all gearboxes may be monitored through one precise readout and control unit.

Work continued on defining the interface between the computer to be used for orbit computations in the LET and the antenna control system. Group 76 will furnish the equipment for the complete analog closed-loop system and also the equipment necessary to receive and utilize digital pointing information from the computer. Design was started on power wiring, switching, and control system interconnection for the LET.

II. LINCOLN EXPERIMENTAL SATELLITE (LES)

Design of the satellite and booster assembly is approximately 50-percent complete. Manpower buildup was late and has caused us to reduce the time allocated for test and qualification. Mechanical fabrication is on schedule.

A. Satellite Structure

The frame, hub casting, and tooling designs for the satellite structure have been completed. Prototype assembly of the first satellite frame for design proof testing is scheduled to start on 1 July 1964.

DIVISION 7

B. Solar and Antenna Panels

Design of the solar-panel honeycomb substrates was completed and the first panel has been fabricated. To improve thermal radiation properties of the panels, the inside of the panel will be painted black and the outside will be fitted with aluminized glass reflector segments in the areas not covered by solar cells. Preliminary design is in progress to add an electrical connector to these panels to provide reliable wiring connections.

C. Spin Table

A prototype model spin table has been built and is ready for testing. The prototype version is slightly smaller in diameter than the flight model but is otherwise identical. The model will be used to determine the feasibility of the system and the separation parameters under ambient conditions. It will also be used to calibrate the energy of the system through the expected flight temperature range. Design of the flight version has been completed.

D. Satellite Support

The satellite support and ejection mechanism has been designed and is currently being fabricated. Alternate techniques for supporting the satellite are being investigated. One system consists of the previously described four ball-and-stud and collet units individually supported and actuated by an explosive actuator.

E. Satellite Vibration Tests

During this quarter, the 25-pound dummy satellite was subjected to new vibration test specifications as required by the Titan III vehicle. Results of these tests are currently being analyzed. Future tests will include the same vertical and horizontal vibration tests, but a 175-pound steel casing about 32 inches high will be attached to the dummy satellite to simulate the rocket motor, spin mechanisms, and housing assemblies.

F. Satellite Test Program

The general plan of the program is to perform functional tests on each component, sub-assembly, and final assembly. This will be followed by performance testing with simulated environmental conditions.

One of the first tests planned is the simulator test on the spin and ejection mechanisms. The purpose of the test is twofold: (1) to determine the behavior of a mechanical model of the satellite under the influence of spin-up and ejection, and (2) to determine the performance of the spin-up and ejection mechanism.

III. PROJECT WEST FORD

Preparations were completed for replacing the existing hydraulic drives with Ward-Leonard electric drives on the East Coast West Ford mount. This will be done during the next quarter.